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ABSTRACT

The use of numerical simulations to design and analyze new products requires both conceptual and operational knowledge. This paper describes COMPANION: an intelligent multimedia system for vocational training used by engineers and technicians. A key concept in terms of training methodology is that of "situated learning," or continuous learning in the workplace. Cognitive apprenticeship is a design model supporting situational learning which is an extension of the traditional apprenticeship model focusing on learning problem solving skills in the practice of performing authentic tasks. The novice (apprentice) watches the expert performing the task, and the expert allows the novice to ask questions and perform small parts of the task, with the amount of the task carried out by the novice increasing as experience is gained. Following an introduction in section one, section two describes the different student uses of COMPANION, and shows how cognitive apprenticeship and hypermedia are integrated in the whole system. Section three focuses on the structure of COMPANION. Section four details the content of hypermedia modules used in conceptual knowledge acquisition. Section five describes how the operational knowledge is structured and acquired. Sections six and seven, respectively, detail the engineering activity and the technical assistant, which embodies the knowledge that becomes operational during problem solving with collaboration between the student and COMPANION. (Contains 17 references.) (Author/MAS)

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COMPANION : An interactive learning environment based on the cognitive apprenticeship paradigm for design engineers using numerical simulations

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Abstract: The use of numerical simulations to design and analyze new industrial products requires both conceptual and operational knowledge. This paper describes COMPANION: an intelligent multimedia system in vocational training. The system is used by engineers and technicians on-line during their work in a company. A key concept in terms of training methodology is that of "situated learning" or continuous learning in the workplace.

1. Introduction

During the design of new products, some engineers are involved in computer simulations to analyze the behaviour of the product with complex and specialized tools called Finite Element Simulation Softwares (FESS). As all complex computer tools, the traditional help systems in the form of on-line manuals and interactive tutorials are not efficient to master the corresponding tools [Larsson, J.E., Persson, P. 1988; Matthews, M.M., et al. 1988; Sandberg, J., et al. 1988]. In addition, in educational context a computer-based simulation should have additional knowledge (conceptual) of the domain in order to provide the user with a more deep understanding of the underlying model [Berkum, J.V., et al. 1989]. Finally, a FESS is a Computer Aided Engineering (CAE) tool where difficult tasks such as modelling, solving and analyzing engineering problems are performed. Thus, the use of a FESS is not simply limited to the knowledge of the commands but requires also the knowledge of the problem solving methods. On the other hand, in industrial (vocational) training contexts, the main objective is improving qualification and proficiency, i.e. acquire operational knowledge (skills) through repeated experiences of related tasks. To achieve all these features, computer-based environments for FESS should integrate both conceptual and operational knowledge acquisitions. In our research, a key concept in term of vocational training methodology is that of "situated learning" or continuous learning on the workplace, i.e. in the culture and context of actually performing the task. A design model supporting situated learning is cognitive apprenticeship which is an extension of the traditional apprenticeship model focusing in learning problem solving skills in the practice of performing authentic tasks [Collins, A., Brown, J. S., and Newman, S. 1989]. The novice (apprentice) watches the expert performing the task and the expert allows the novice to ask questions and perform small parts of the task with the amount of the task carried out by the novice increasing as experience is gained. Instructional principles are: modelling, coaching, scaffolding, fading, articulation and reflexion. This approach seems the most promising for teaching/learning operational knowledge [Cooper Eric, B. W., 1991; Tong, T. 1993; Newman, D. 1989]. For conceptual knowledge, the use of hypertext and hypermedia techniques [Duffy, T.M., Knuth, R.A. 1990; Honebein, P. C., et al. 1992] reveals efficient for adults which want more free browsing among knowledge items.

Section 2 describes the different activities of the student in COMPANION and shows how cognitive apprenticeship and hypermedia techniques are integrated in the whole system. Section 3 focuses in the structure of COMPANION. Section 4 details the content of hypermedia modules used in conceptual knowledge acquisitions. Section 5 describes how the operational knowledge is structured and acquired. Section 6 and Section 7 details, respectively, the engineering activity and the technical assistant which embodies the knowledge that become operational during problem (small projects) solving with collaboration between the student and COMPANION. This paper ends with a conclusion and feature research.

2. COMPANION overview

The COMPANION system is primarily aimed at technical staff (technicians and engineers) using FESS in structural dynamics applied to the fields of stamping (sheet metal forming) and occupant safety. Stamping simulation addresses large manufacturing companies as well as their smaller sized subcontractors. Consequently, the technical staff being trained may have little academic background in mechanics and little or no knowledge in CAD (Computer Aided Design)/CAE(Computer Aided Engineering), but in general plenty of

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experience in their own field of technology. For occupant safety, the user community is mainly in the automobile industry, and is more acquainted with CAD/CAE concepts.

COMPANION distinguishes three levels of students:

Base student. He/she has an acceptable level of mechanical engineering and little experience of the finite element method (or none at all). The system is not intended to teach him/her the finite element method. It teaches him/her practical rules of use of the FESS[1]. As a result, the student will be able to perform robust calculations of acceptable quality, mostly elementary calculations and parametric studies.

Intermediate student. He/she has a good experience of standard finite element tools and knows the implicit integration scheme. The system teaches the explicit integration scheme and the particular use of it in the FESS. As result, the student will be able to perform industrial calculations.

Advanced student. He/she has already used non-linear dynamic tools which use the explicit integration scheme. The system teaches the advanced methods of the profession. As a result, the student will completely overcome the FESS.

With a set of questions, the system evaluates the initial level of the student and selects a set of hypermedia modules corresponding to a certain level of use of the FESS (e.g. performing parametric studies). The student can then explore at his/her own pace the different modules which provide a conceptual view of the objects in the domain that are important to performing the tasks, and also their relationships to one another. For example, the contact modelling module (see figure 1) introduces the basic concepts (physical and numerical) required for running FESS. Once the student has explored this module, the system assumes that he/she can use the contact function in the FESS. The student can insert comments and record sound in the hypermedia modules to inform the system that he/she does not understand a concept, he/she needs an example, more detail and an animation. Thus, no evaluation is done to insure that the student is acquiring the knowledge represented in the modules in a way that will be useful to performing the tasks in which he/she is being trained. But, the system checks after each module to see if there is a message left by the student. If there is a message, the system generates a file message to the author of the module. While the student is progressing through the modules, a list of available exercises and problems is updated which are all relevant to the knowledge already acquired. Exercrises (see figure 2) are elementary applications on parameters influence where the system allows the student to choose between values and obtain from the system interpretations and evaluations of the simulation results and comments about the choices.

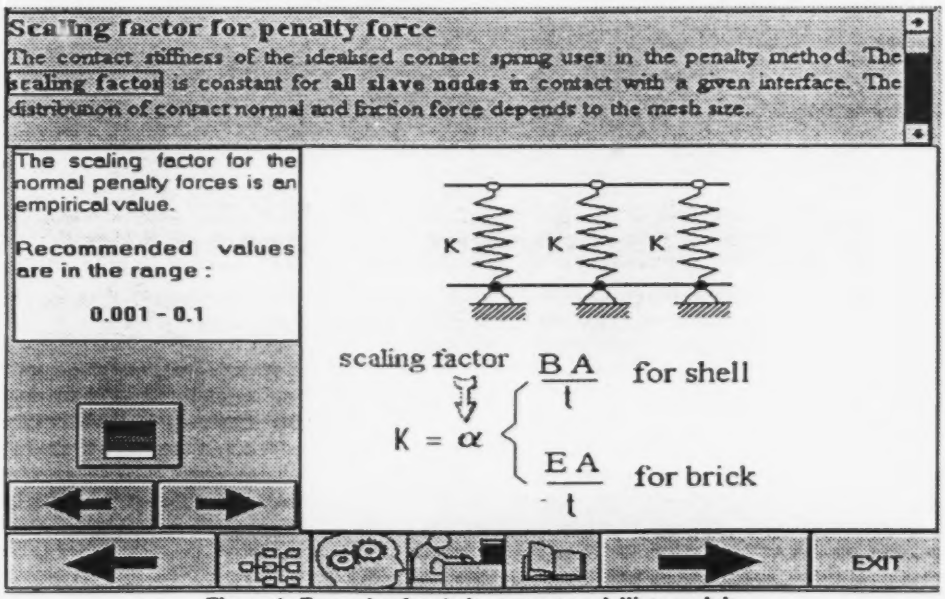
Scaling factor for penalty force
The contact stiffness of the idealised contact spring uses in the penalty method. The scaling factor is constant for all slave nodes in contact with a given interface. The distribution of contact normal and friction force depends to the mesh size.
The scaling factor for the normal penalty forces is an empirical value.
Recommended values are in the range :
0.001 - 0.1
K
K
K
scaling factor
K = α
B A / t
for shell
E A / t
for brick
EXIT

Figure 1: Example of node in contact modelling module

[1]We use the software PAM-SAFE™ for safe and PAM-STAMP™ for stamping.

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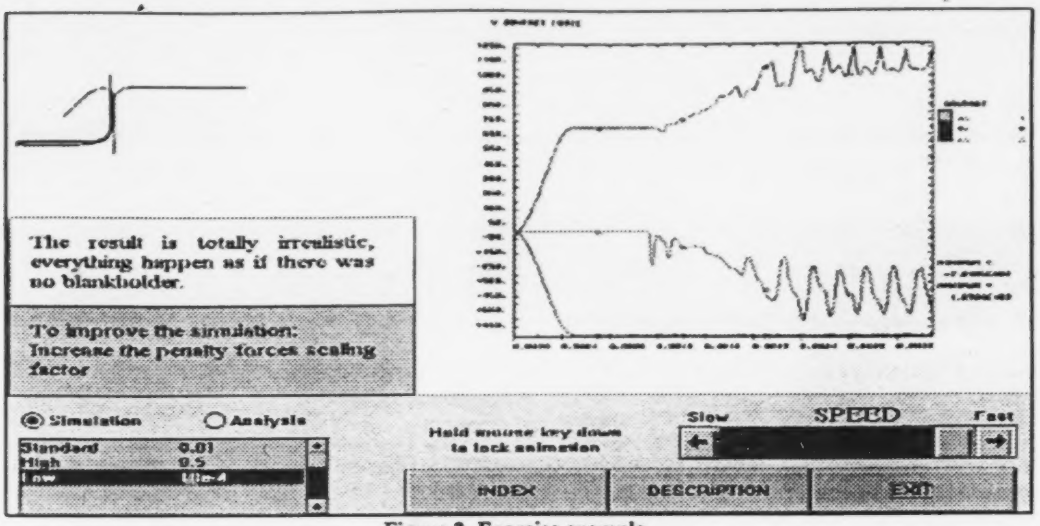

Figure 2. Exercise example

Problems are small projects that cover all the concepts introduced in the modules explored by the student. When the student activates the problem solving, the system execute the two following steps : Standard case - the objective is to focus the student on the knowledge of the use of tools. The system guides the student from general knowledge (sequences of tasks and subtasks) to specific knowledge (sequences of commands). Sensitivity analysis - the main objective is to acquire experience in the analyze of a product by altering parameter values. When the student changes the values, the system provides interpretations of the results (see figure 1 - explanation window) and comments (e.g. "You have increased material density and obtained CPU gain", "Homogenenous strain in specimen - the solution is acceptable", "Strain localized in head specimen - the solution is not acceptable") according to the success criteria associated with the problem. When the student is asked to change a value in order to reach a certain goal (e.g. increase stability, increase cpu gain, reduce the blankholder displacement) the system gives hints (e.g. "When no pressure is applied, material model 100 leads to a significant reduction of running and the storage size", "The iterative method, model 103, leads to a more accurate solution for quadrilateral shells with isotropic yield criterion").

3. COMPANION architecture

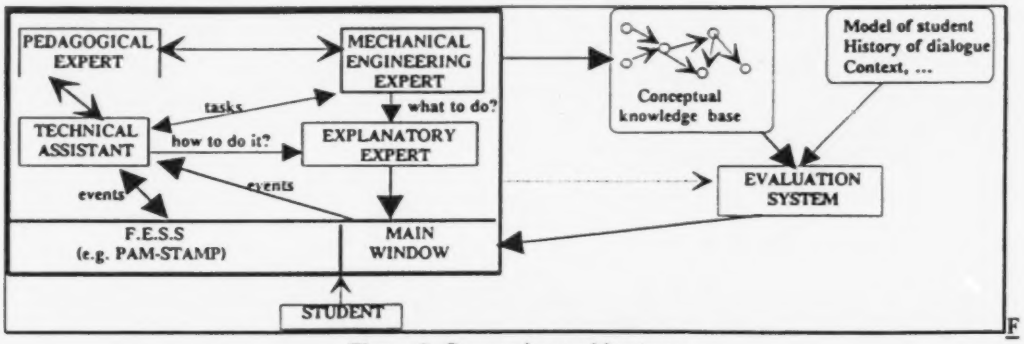

Figure 3. Companion architecture

COMPANION (see figure 3) is a multi-agent system [Futtersack, M., Labat, J.M., 1992] that comprises knowledge-based systems and hypermedia modules: A conceptual knowledge base that contains a detailed description of the modelled domain (network of hypermedia modules); An evaluation system that provides the right hypermedia modules corresponding to the student's level; A pedagogical expert which embodies the model of cognitive apprenticeship; A mechanical engineering expert that contains general engineering knowledge: tasks (e.g. modelling the problem domain), sub-tasks (e.g. adapting the mesh to the objectives of the analysis) and production rules for terminal decisions (e.g. choice of time increment); A technical assistant expert that contains specific knowledge, i.e. functional description of tool interface in term

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of commands; An explanatory expert that responds to specific requests of the student and provides coherent integrated explanations of both conceptual and operational knowledge. It can also activate a node in a module to provide more details or an animation. COMPANION uses authentic FESS. Thus another functionalities (not visible to the student) are added to the interfaces used in the FESS in order to satisfy the requirements of COMPANION: to be able to proceed the problem solving and to be informed of what is happening in the interface. Each interface is a task (in a multi-task environment) which communicate by messages with the technical assistant.

4. The conceptual knowledge base

The conceptual knowledge base (CKB) contains a detailed description of the modelled domain, the basic assumptions and hypotheses underlying the model (e.g. kinematic hypothesis, contact algorithm), the definitions of concepts, and the meaning of parameters and variable values (e.g. a description of critical values or typical values of variables). This CKB is organized as a hierarchy of hypermedia modules which can be performed independently. Each module has prerequisite relationships and/or isa specialization relationships to the other modules. In a module several concepts are introduced. They are grouped under four categories:

Relevant physical concepts. These part of the modules provide a good physical understanding of the concerned phenomena and an overview on the theoretical considerations needed for the proper resolution of the industrial problems of the student.
Modelling. The modelling aspects are discussed in order to provide a good understanding of the input parameters and the ability to realise reasonable models of the analysed phenomena.
Practical considerations. The specificity of each type of analysis (here stamping or occupant safety simulations) allows the student to access for hints about classical pitfalls.
Exercises. Made accessible by the system when the student has been studying the relevant parts of the module. These exercises are elementary applications (variable assignment exercises) that provide a more understanding of concepts and principles underlying the model. The student is free to choose values to assign to certain variables or parameters and watch, in real time, the development of the state of the model. The system evaluates the given answer to give some comments and interpretations of the results.

Much of phenomena (e.g. self-contact, airbag and stamping) are illustrated by synchronizing animation and sound. Hotwords are also used to trigger pop-up explanations of terms in a text or branch to other nodes.

5. Pedagogical expert

A FESS provides an infrastructure for accomplishing engineer's tasks, i.e. the various activities appear as objects in the screen like the names of menus, dialogue boxes, fields to type in, or buttons. The interface of FESS is generaly an event-driven system where nothing happens until an event occurs. Events result from user actions such as clicking a mouse button, pressing a key, moving the mouse on the screen, or choosing a menu item. We define the student interaction with the FESS as a sequence of operations that are performed upon the interface to do a task. When there is a normative sequence of input and output associated with the interaction we will speak of procedure or skill. The distinction between a procedure and a skill is that the student can have knowledge about procedures without being particularly 'skilled' in executing them. To take into account of some sources of cognitive difficulties [Waern, K. G, 1991] in the interaction with the FESS, the pedagogical expert uses two attributes: ***Task complexity:*** estimates the effort that is required to learn how to master the sequence of operations that compose the task. This attribute takes three values: very complex, complex and simple. The basic idea is that integrating command sequences as procedural knowledge (more or less automatic) for the most frequent work tasks is done quite quickly. ***Memory-problems:*** depending on the number of zooming operations and the time response of commands that are in the task, the pedagogical expert affects to this attribute one of these values: much, few and no. The basic idea is that tasks using the zooming function to enlarge mesh details present some short term memory problems, in that the student may lose the perception of the totality of the mesh. In addition, the computer takes in several cases long time to respond to certain commands and could also introduce short term memory problems. The typical situation in such cases is that the student is conceptualizing a sequence of procedural operations.

The operational knowledge is organized into general knowledge (mechanical engineering expert) which determines what to do and specific knowledge (technical assistant) which determines how to do it. Both general and specific knowledge are acquired in the context of solving a library of problems with collaboration between the student and the system. These problems are grouped according to the level of use of the FESS. The

student go over this library from base to advanced level of use. The student has the overall control on problem solving. He/she decides whether to interrupt the resolution and proceed or whether to stop and ask the system to proceed. The system interventions on student failures are immediate in coaching stage and are wait-and-see [Galdes , D. K., et al.,] in fading stage. The system evaluates student actions in terms of the expert understanding of the task [Newman, D. 1989].

Depending on the student's model, the objectives of the problem, the level of use of the FESS, the focus knowledge (use of the tool, comprehension of the product physics, compehension of the task of an engineer, improve the performance of a certain skill), the pedagogical expert selects one or more different intervention types during the resolution of a problem. The intervention types are: to accompagny (e.g. "Lets choose the units"); to direct (e.g. "Introduce the material properties"); to take care by forbid some uses (e.g. "Do not use physical contraints for the tools") or by prevent for the eventuel errors (e.g. "Be sure that the sheet mesh is regular"); to reduce the difficulty (e.g. breaking a goal into its subgoals), summarize, demonstrate a goal; to maintain the orientation in comparison with the principal goal or to the intermediate goals (e.g. to remind the goal); to indicate the decisive characterestics (e.g. provide the useful information to proceed); control the frustration (e.g. provide evaluations, encouragements); to scaffold, i.e., provide a set of mechanisms that enable the student to perform a task, but which fade away as the student becomes more expert (e.g. disable all menu items in the interface that are not useful to perform the task in foccus, or highlight a menu item). This is what called [James A., et al., 1988] dynamic support which is derived from the learning principle referred to as "the zone of proximal development" [Vygotsky, 1986]. The pedagogical expert is a knowledge-based system where each intervention type is implemented as a set of production rules. Another rules maintains the student model (overlay model) after each problem solving.

6. Mechanical Engineering Expert (MEE)

The MEE is a knowledge-based system that contains engineering expertise. It contains a knowledge base structured into two levels: strategic level and a tactical level. The strategic level is described by a set of plans that organize the overall control of problem solving. The tactical level is a set of production rules that make different terminal decisions like the choice of material type, the choice of variable/parameter values. The strategic level is tool independent but the tactical level is tool dependent as shown in the following examples:

Plan 1 **Objective:** resolve a problem **Actions:** (preprocessing, resolution, postprocessing)[2]	**Rule 5** **If** the problem is to improve the stability of the computation **Then** define two bead interfaces, one against each surface of the sheet.
Plan 4 **Objective:** introduction of complementary data **Actions:** {Nodal restraints, Load definitions, Slide interface, Material properties, Control data}	**Rule 11** **To** introduce an equivalent drawbead between the sheet, the blankholder and the die **Use** the model type 4.

Table 1: Plans and rules examples

The MEE contains also a plan-interpreter KEPLER-OBJECT which is an extension of KEPLER [Futtersack, M., Labat, J.M. 1993; Vivet, M. 1988] to allow collaborative solving and object-oriented features.

7. Technical Assistant

The Technical Assistant monitors student's interactions with the FESS, makes the useful suggestions to the student about FESS capabilities in the context of current activities and facilitates the accomplishment of a particular task by a student who does not currently know how to do it. It contains a network describing the FESS interface. At the meta level, the nodes represent tools and the links represent events that define the action to perform on an object in order to access to another tool. A tool-node contains a hierarchical organization of actions as they appear in the interface of the FESS. The lowest level correspond to elementary actions (e.g., choice of material model, introduce parameter value) whereas higher level nodes correspond to abstract tasks (e.g., creating the mesh, introducing complementary data, analyzing results) that are executed as a sequence of sub-tasks. (A sub-task could be either a simple action or another sequence of sub-tasks). A sequence of events is associated for each action in order to know how to perform it. The choice of what prompt to give and/or how to do a task are implemented by searching a path between the current state and the goal state. A current state is defined by a set of all visible objects and the goal state by a set of objects that will be visible in order to perform the desired task. The path contains the sequence of events that allow the transition between these two states.

[2]ordered actions are between () and independent actions are between {}.

Depending on the intervention type selected by the pedagogical expert, this exhaustive path is pruned before submitted to the explanatory expert.

8. Conclusion

A prototype COMPANION has been implemented on a PC/Windows platform using TOOLBOOK for multimedia aspects, KAPPA for rule based and oriented-object techniques and KEPLER for the planning. This prototype is tested by some end users and evaluated by trained specialists. The results are globally positive especially for the global philosophy of COMPANION: hypermedia techniques for conceptual knowledge and cognitive apprenticeship for operational knowledge. The organization and the structure of the modules are appreciated and steel the same for the end product. Actually, we improve the expertise of the different knowledge-base systems and add another functonality to the system, where the student can express his/her hypothesis, interpretations and evaluation of the simulation results. Further experimental studies with COMPANION are also planned.

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